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TITLE
SLOT DIE
BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to slot dies for forming a coating on a substrate and casting films. More particularly, this invention relates to a slot die constructed to control the thickness profile of a coating across the die width, and to the use of that die.

2. Description of Related Art

Slot dies form a flowable material, such as a solvent solution, an emulsion, a thermoplastic melt, a radiation curable oligomer and the like, into a sheet, film, or web. In a common application in the coating industry, a solvent solution of a coating material is moved into an inlet, through an internal distributing cavity, and discharged from an orifice (also known as an exit) to form a ribbon of material which is coated onto a substrate and concentrated by evaporation to continuously form a supported sheet, film, or web which can be wound into a roll. The die takes a stream of flowable material and spreads it internally to form a discharging ribbon with a large width-to-thickness ratio.

Coatings may also be applied by slot dies to substrates other than continuous webs such as discrete parts or sheets cut from a web which are passed singularly or in arrays through the coating station. After the deposition of a coating, it can remain a fluid such as in the application of lubricating oil to metal in metal coil processing or the application of chemical reactants to activate or chemically transform a substrate surface. Alternatively, the coating can be dried if it contains a volatile fluid to leave behind a solid coat such as a paint, or can be cured or in some other way solidified to a functional coating such as a release coating to which a pressure sensitive adhesive will not aggressively stick.

It is known that different flowable materials processed under a variety of conditions through a slot die can deform a slot die orifice to different extents, producing a ribbon of material of uneven thickness. A highly viscous material coated at a high rate of speed may require high pressure pumping which can generate high pressures within a slot die cavity. High pressures are capable of deforming a slot die, and the pressures are generally not uniform within the cavity. Materials introduced into a slot die cavity at high temperatures can also deform a die orifice

from its original shape due to forces generated by dimensional changes in the slot die due to the coefficient of thermal expansion of the slot die.

It is known to provide dies with various manual mechanical, thermomechanical, piezomechanical, magnetostrictive, or motor driven actuators for moving the die lips to provide control of the film, sheet, or coating thickness. This control is produced by controlling the local flow rate of fluid exiting across the width of the die from the slot orifice of the discharge slot at the external surface of the die body by adjusting the orifice gap.

Usually, control is accomplished by measuring the thickness of the film or coating at various points across its width with a thickness gage such as beta-ray, X-ray, or light absorption gage. With the information from such a measurement, an operator can manually adjust a bolt type actuator bearing against the lip. Alternatively, a control system can signal the activation of actuators which bear against the lip or which rotate bolts that bear against the lip. The manual adjustment of die lip flexing bolts by an operator requires skill and experience. It has been shown that the quality of product extruded or coated can be improved by a closed loop control system to replace the manual operator adjustment.

U.S. Pat. No. 5,587,184 (W. K. Leonard, et al.) teaches a method to adjust the die slot orifice gap to produce a controlled flow from the slot orifice across the width of a die by providing movable back seats at the back of the die that cause the front and back portions of the die plates to move simultaneously to produce a change in the die slot orifice gap. At least one actuator is located between the front and back seats of the die to increase or reduce its length to bend the upper plate around the front seat thereby to increase or decrease the die orifice gap.

It is known to provide dies with shims to effect a variety of die slot orifice gap sizes. U.S. Pat. No. 5,894,994 (J. J. Keane, et al.) provides an adjustable slot die which comprises upper and lower die halves secured together and having a replaceable shim of varying thickness there between. Keane et al provides a lip insert adjustment mechanism for adjusting the position of a removable lip insert with respect to the front of a slot die.

U.S. Pat. No. 5,500,274 (D. C. Francis, et al.) provides composite coatings having a variable thickness and a gradient coloration in the cross-web direction using a premetered extrusion coating process wherein a pigmented coating composition and a non-pigmented coating

composition are simultaneously extruded onto a carrier film. The composite coatings are useful in preparing laminated structures such as automobile windshields with a colored gradient band.

SUMMARY OF THE INVENTION

The present invention relates to a die comprising a first plate having a first lip, a first location, and a second location where the first location is between the second location and the first lip; a second plate having a second lip, a third location, and a fourth location where the third location is between the fourth location and the second lip the second location of the first plate being a distance away from the fourth location of the second plate; and a shim having a top seat and a bottom seat; the top seat of the shim contacting the first plate at the first location and the bottom seat of the shim contacting the second plate at the third location, so as to form a slot in the die which terminates at an orifice and is bounded at the orifice by the first and second lips, the first and second lips having a gap there between, the gap having a size; and a means for adjustably connecting the first plate to the second plate at the second location and the fourth location such that the size of the gap between the first and second lips is adjustable by adjusting the distance between the second location of the first plate and the fourth location of the second plate.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention can be more fully understood from the following detailed description thereof in connection with the accompanying drawings described as follows:

Figure 1 is a cross-sectional perspective view of a coating die of the prior art.

Figure 2 is a cross-sectional view of an orifice of each of four coating dies depicted as A, B, C, D, of the prior art.

Figure 3 is a cross-sectional view of a slot die of the prior art.

Figure 4 is a perspective view of a first embodiment of a slot die of the present invention.

Figure 5 is a break-away planar view of a top side of the slot die of Figure 4.

Figure 6 is a cross-sectional view of the slot die taken along lines 6-6 of Figure 4.

Figure 7 is a cross-sectional view of a second embodiment of the slot die of the present invention.

DETAILED DESCRIPTION

Throughout the following detailed description, similar reference characters refer to similar elements in all figures of the drawings.

Figure 1 is a known slot die **1** showing the common features for flexing a top die lip **2** to adjust the profile of the fluid flow from the die across its width. A flowable material is forced to flow into the die body **3**, which has a first half or top plate **4** and a second half or bottom plate **5**. The material can be distributed within the die using a feature such as a trough **6**. The material exits from the die slot orifice **7** (also known as an orifice) of the slot **8**. The top plate **4** and bottom plate **5** mate at the middle die seat **9** and rear die seat **10**. Adjacent the orifice **7** and on a side opposite the rear die seat **10** are the top die lip **2** and a bottom die lip **11**. As is conventional in the art, a plurality of mechanical actuators (not shown) may be used to apply pushing or pulling forces, F_1, F_2, F_3, . . . F_n, spaced across the width of the die. These actuators must physically attach to at least one die lip **2**, **11** or cause movement of some physical linkage that bears against or is attached to the die lip **2**, **11**. Known actuators include translating bolts, thermally expanding bolts, piezoelectric actuators, magnetostrictive actuators, motor driven actuators, and hydraulic actuators. Movement by these devices changes an orifice gap **g**, also called the orifice height. Non-uniform application of the forces **F** can produce local changes in the orifice gap **g** in some limited region across a width of the die **1**. Because the local flow rate from the die slot orifice **7** is influenced by the local orifice gap **g**, the material discharge rate may be adjusted across the horizontal width of the die slot orifice **7** to achieve a given profile of the ribbon of material.

A common profile (also known as a transverse direction cross-section) for the arbitrarily long ribbon of material flowing from the orifice is essentially a rectangle with a constant height determined by the orifice gap **g**, and a constant width determined by the horizontal width of the orifice **7**. The orifice height **g** is typically small relative to the horizontal width of the orifice **7**.

Figure 2 shows profiles along the orifice of known slot dies. Figure 2A shows a (lower) flat surface die plate **12** attached to an (upper) convex die plate **13** which form a plano-concave orifice **14**. Figure 2B shows the same (lower) flat surface die plate **12** attached to an (upper) flat surface die plate **15** which form a rectangular orifice **16**. Figure 2C shows the same (lower) flat surface die plate **12** attached to an (upper) concave

die plate **17** which form a plano-convex orifice **18**. Figure 2D shows the same (lower) flat surface die plate **12** attached to a shim **19** which is attached to the same (upper) flat surface die plate **15** of Figure 2B to form a rectangular orifice **20** higher than the orifice shown in Figure 2B.

Low viscosity material pumped at low temperature and a low rate of ribbon extrusion through a plano-concave orifice might not appreciably change the orifice profile from plano-concave; however if higher viscosity or higher temperature material is used at the same rate of ribbon extrusion, the slot die orifice can deform to form a rectangular or even plano-convex orifice profile. Higher rates of ribbon extrusion, or any combinations of the previously mentioned changes and other well known and commonly experienced changes, can also deform the slot die orifice, for example to form a rectangular or even plano-convex orifice profile from an initially plano-concave profile.

It is desirable to provide conditions to utilize a single set of die plates for extrusion of a wide variety of materials under any of a wide variety of conditions to produce a wide variety of desired ribbon profiles at a wide variety of extrusion rates with only simple adjustments. Such conditions can be described as robust. Because modification of a die plate can be expensive, time-consuming, and irreversible, it is less desirable or even impractical to achieve a wide variety of results by modification of a die plate.

Figure 3 is a cross section of a prior art slot die. The die body includes a top plate **14** and a bottom plate **15** which contact each other. The top plate mates on the bottom plate at the seats **22**, **23**, to form a slot **18** with trough **16** through the die body to the right of the seat **22**. Flowable material can be forced from the interior of the die body through the slot **18**. The slot **18** terminates and is bounded at its orifice by top and bottom lips, which are the ends of the top and bottom plates **14**, **15**, to the right of the front seat **22**.

A cutout **24** is formed in the die plate under the back seat **23** of the bottom plate along at least part of the width of the die. A plurality of means of adjustment or equivalently actuators **25** are inserted into this cutout between a lower actuator seat and an upper actuator seat. The actuators can increase or reduce their length to move the back seat **23** away or toward an actuator seat.

When the actuator **25** lengthens, the top plate **14** at the back seat **23** moves up and pivots around the front seat **22** forcing its top lip

downward to close the orifice gap. Similarly, when the actuator **25** shortens, the top plate **14** at the back seat **23** moves down and pivots around the front seat **22** forcing its top lip upward to open the orifice gap. Non-uniform application of only some actuators can produce local changes in the orifice gap in some limited region across the width of the die. In this manner, because the local flow rate from the orifice is influenced by the local gap, the material discharge rate can be adjusted across the width of the die.

An additional cutout **26** is formed on the top of the bottom plate **15** to facilitate the compression. The cutout **26** is bounded by the two seats **22, 23** and a bridge **27**. The increase or decrease of the linear distance between the actuator seats, caused by the actuators **25**, causes changes in the stresses through all portions of the plates **14, 15** and die bolts **28**, and causes the elastic deformation of these pieces. To cause the movement of the top lip relative to the bottom lip to change die orifice gap may require that the bottom plate **15** design allow the front seat **22** to deform elastically while most of the bottom plate **15** remains stiff and relatively unbending. It also requires the die bolts **28** to elastically stretch to avoid impeding movement of the top plate **14** in response to the movement of the actuator **25**. Also, the top plate **14** should be rigid and stiff enough so that at least some portion of the movement of the seat **22** in conjunction with the clamping force of the die bolts **28** causes movement of top lip with respect to the bottom lip to change the orifice gap.

The difficulty of producing die plates to these specifications is apparent to those skilled in the art. A single die plate produced to these specifications may not have a desirable level of robustness to produce a range of die orifice profiles. The combination of any two die plates by the teachings known to the art is limited in the range of die orifice profiles which can be practically achieved by the actuators or other methods which are known in the art.

Figure 4 is a preferred first embodiment of a slot die **29** according to the present invention. The slot die **29** includes a first plate **30** having a first lip **30a**, a second plate **31** having a second lip **31a** and a shim **32** having a first seat **36** and a second seat **38**.

The slot die **29** includes a means of attaching **34** the first plate **30** to the shim **32**, and the second plate **31** to the shim **32**. In one example, a plurality of connecting bolts and nuts (not shown in Fig. 4) can serve

simultaneously as both means of attachment. The means of attaching **34** the second plate **31** to the shim **32** can be independent from or can be the same as the means of attaching **34** the first plate to the shim. In this case, the first plate **31**, the shim **32**, and the second plate **31** include a plurality of through holes (not shown) which are formed in the first and second plates **30, 31**. The through holes can be formed by drilling.

The first plate **30** contacts the shim **32** and the first seat **32a** and the second plate **31** contacts the shim **32** and the second seat **32b** to form a slot **36** in the die **29** which terminates at an orifice **39** and is bounded at the orifice **39** by the first and second lips **30a, 31a**, the first and second lips **30a, 31a** having a gap therebetween. The through holes of the first and second plates **30, 31** are placed in alignment with the shim **32** located therebetween. The first and second plates **30, 31** are fastened securely together by a means of attachment **34** which penetrates through the aligned holes.

Flowable material is supplied to the slot die **29** by a material inlet port 33 located in the first plate **30**. (The material inlet port could have alternatively been located on the second plate **31** or at any other convenient location.) The flowable material can form a coating, preferably a continuous coating, on a substrate in accordance with any known slot die coating processes.

The slot **36** is adjusted in height by a plurality of means for adjusting **37**. The means for adjusting **37** changes the shape of the orifice from the slot **36**. The means for adjusting **37** in this illustrative case comprises a compressible spring **40**, a spring-holding bolt **41**, and an adjusting nut. The spring-holding bolt **41** has a head, a shank and a stop. The compressible spring is positioned above the first plate **30** and the head of the spring-holding bolt **41** is positioned above the compressible spring **40**. The shank of the spring-holding bolt **41** extends through the compressible spring **40**, a first bore hole (not shown in Fig. 4) of the first plate and at least partially through a second bore hole (not shown in Fig. 4) of the second plate **31**. When the spring holding bolt extends fully through the second plate such that a portion of the shank protrudes through the second plate, a nut (not shown) located below the second plate **31** may be fastened to the stop. Thus, each spring-holding bolt **41** can be longer than the combination of the thickness of the first and second plates **30** and **31** and the shim in order to extend out from the slot die. In this embodiment,

the compressible spring can be in compression and exerting a force against an outer location of the first plate **30**.

Figure 5 shows separate top views of the first plate **38** (5A), the shim **42** (5B), and the second plate **44** (5C) as if the die had been disassembled by the removal of all the means of attaching and means for adjusting to better show the upper surface shape of the shim and the second plate. The first plate **38** is penetrated by an inlet port **39** which serves as the material inlet port, a first set of attachment holes **40** (each identified by an imaginary horizonal line within the hole) used to accommodate the means of attaching to hold together the first plate **38**, shim **42**, and second plate **44**; and a first set of adjustment holes **41** (each identified by an imaginary vertical line within the hole) to accommodate the means for adjusting. The first shim **42**, has a second set of attachment holes **43** which correspond in position to the first set of attachment holes **40**. The second plate **44**, has a third set of attachment holes **45** and a second set of adjustment holes **46**. The second set of attachment holes **32** are aligned with the first and third sets of attachment holes **40**, **45** to accommodate the means of attaching. The first and second sets of adjustment holes **41**, **46** are aligned to accommodate the means for adjusting.

Figure 6 illustrates in cut-away a preferred embodiment of a slot die **45** of the invention, comprising:

a first plate **46** having a first lip **47**, a first inner location **48**, a second inner location **49**, and a first contacting location **50**,

where the first inner location **48** is between the second inner location **49** and the first lip **47**;

a second plate **51** having a second lip **52**, a third inner location **53**, a fourth inner location **54**, and a second contacting location **55**,

where the third inner location **53** is between the fourth inner location **54** and the second lip **52**;

a shim **56** having a first seat **57** with a first seat width **w1** and a second seat **58** having a second seat width **w2**,

a first means of attaching **59** which serves to connect the first plate **46** and the shim **56**,

whereby the third means of attaching **59** causes the first plate **46** at the first location **48** to contact

the shim **56** at the first seat **57** along its first seat width **w1**;

a second means of attaching **60** which serves to connect the second plate **51** and the shim **56**,

whereby the fourth means of attaching **60** causes the second plate **51** at the third inner location **53** to contact

the shim **56** at the second seat **58** along its second seat width **w2**,

such that the shim **56** separates the first plate **46** from the second plate **51** forming a

slot **61** which terminates at an orifice **62** which is bounded at the orifice **62** by the first and second lips **47**, **52**;

where the orifice **62** defines a first gap height **g1** between the first lip **47** and the second lip **52**;

and

a means of adjusting a first adjustment distance **d1** between the second inner location **49** and the fourth inner location **54** such that the first adjustment distance can be lengthened or shortened to adjust, by shortening or lengthening, the first gap height between the first lip **47** and the second lip **52**.

A preferred embodiment of the slot die of the invention is exemplified above, wherein the first and second means of attaching both comprise a single set of bolts and nuts **63**, and the means of adjusting comprises a plurality of separate assemblies, which comprise

a first spring **64** and a first adjustable coupling member **65**, shown here as a third bolt and nut,

where the first spring **64** is configured in contact with the first adjustable coupling member **65**, and exerts a first force **Fd** onto the first plate **46** at the first contacting location **50** and

exerts a second force **Fu** on the first adjustable coupling member **65** at a coupling member location **66**, and the first adjustable coupling member **65** contacts the second plate at the second contacting location **55**.

Figure 7 shows an artist's rendering of a cutaway view of another embodiment of the slot die **67** in the case wherein the means of adjusting comprises

a spring **68** and an adjustable coupling member **69**,

where the spring **68** exerts a third force **Fo** on a first plate **70** at a first contacting location **71** and exerts a fourth force **F4** on a second plate **72** at a second contacting location **73**, and

the adjustable coupling member **69** comprises for example a plurality of an adjustable assembly of a bolt and a nut **74** which contacts both the first and second plates **70, 71**.

Figure 7 also includes optional features which may be useful. For example, a shim **75** located between the first and second plates **70, 72** opposite the adjustable coupling member comprises a first shim layer **76** and a second shim layer **77**. An additional means of attachment **78** is provided and is located between the shim **75** and the adjustable coupling member. A first material **79** is shown flowing from the slot.

In one aspect of the invention a shim is provided which is easily modified or replaced, often more easily and inexpensively than modifying or replacing a plate. A variety of shims can easily be produced which encompass different thicknesses, materials of construction, or physical configurations. For example, either the available thickness or the physical configuration of the shims can easily produce a wide variety of useful orifice configurations (height, width) from a single set of plates.

In another aspect of this invention a shim can be of different thicknesses over the width of the die orifice. If two die plates are of the type shown in Figure 2B, when used with a shim of constant thickness they will form a rectangular orifice as shown in Figure 2D. However, if the shim has a changing thickness over its width which is thicker or larger in the center of its width, the orifice produced from the same two plates may be plano-convex or convex (convex on both sides) depending on the bending imparted on the plates by the shim. If the shim has a changing thickness which is thinner or smaller in the center of its width, the orifice produced from the same two plates may be plano-concave or concave (concave on both sides).

Changes of this sort to a slot die can be particularly important if it is desirable to use a single set of plates with coating solutions of low and high viscosity. Major adjustments of the orifice profile across its entire width can easily be accomplished with the shim of this invention, while minor adjustments are carried out with the means of adjustment which modifies the orifice further and locally.

This invention overcomes problems of high material pressure in the slot. That is, when the material flowing to produce the ribbon generates a high pressure and undesirably forces the first plate in known slot dies upwards and the orifice height to increase. This invention also overcomes

the problem where the material viscosity is low and the flow rate is low, producing a low pressure in the slot.

Often when a die is assembled and not pressurized, there is a slight deflection of the top half toward the bottom half. The deflection is greatest in the center of the width of the orifice, and there is not deflection at the edges where it is supported by the shim. When a solution is coated with low die pressure (e.g. < 10 psig), there can occur what is known as a 'smile' profile - a dip in the center and a rise at the edges, also known as a plano-concave profile. This invention overcomes this problem: to raise the front of the die near the center of the coated product.

The shim of this invention is also useful both when the shim separates the two plates at a single region of contact as shown in Figure 6, or when two or more regions of contact are used, as shown in Figure 7. A shim which separates the plates at a single region can be useful most particularly when low viscosity materials are used. While two or more regions of contact can stabilize a die orifice against changes in the gap due to coatings of material at high pressures, one region of contact can make a die orifice gap more desirably sensitive to changes in the distance at the remote location caused by the means of adjustment, which is particularly useful for materials coated at low pressures.

As used herein, the term “shim” is intended to encompass a wide variety of constructions which can be placed between two plates in order to separate them. For example, a stacking of two identical shims of the type shown in Figure 5B would constitute a “shim” for the purposes of this invention. Similarly, if a construction were made from two identical shims coated on all sides by an adhesive, which were then stacked and inserted between two plates, the construction between the plates would be termed a “shim” for the purposes of this invention. Such a shim would have the additional benefit that the adhesive could serve as the means of attachments of the shim to the plates.

Similarly, the material(s) or physical configuration(s) of a shim can easily produce different and useful responses of the gap height to a given change in the adjustment distance. An elastic material of construction may produce a larger response than an inelastic material. Shims constructed by stacking of layers of different material can produce novel and useful responses. Larger seat width(s) may produce a smaller, more adjustable, response.

A shim made of plastic (such as polyethylene terephthalate) or metal (such as stainless steel, or brass) can easily be cut in a pattern which determines the coated width of the applied material. The thickness of the shim (along with a variety of other factors such as those related to the ribbon material (fluid) viscosity, density, and flow rate) determines the pressure drop through the slot length. In one case, dimensions and material properties are as follows:

Fluid density = 0.9 g/cc
Fluid viscosity = 4 cP
Fluid linear flow = 421 cm/sec
Shim = stainless steel, 0.004" thick

Plates which are useful in the formation of slot dies are well known in the art. Such plates are often made of stainless steel. One type of plate which is useful in the present invention can be purchased from Cloeren Corporation, Orange, TX.

The control of force with spring compression is much more reproducible than the common means of using bolt torque. Springs which are useful in the present invention can be purchased from McMaster-Carr, Cleveland, OH. To improve control of the force applied by the adjusting bolts, heavy-duty compression springs can be inserted between the bolt head and die body. Springs with compression constant of ~700 lbs/inch are available from McMaster-Carr (part #9624K32 or 962K43 for example). Typical spring compression is 0.25".

Those skilled in the art, having benefit of the teachings of the present invention as hereinabove set forth, can effect numerous modifications thereto. These modifications are to be construed as being encompassed within the scope of the present invention as set forth in the appended claims.